Environmental Benefits of Geosynthetics in Construction Projects

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Abstract. The use of geosynthetics has gained increasing attention in recent years due to their potential benefits in various engineering applications. Geosynthetics are used to improve soil structures such as base courses or retaining walls, mostly through reinforcement, filtration, separation, and sealing functions. This paper examines the environmental and economic benefits of using geosynthetics in road, earthworks, and foundation engineering. The paper discusses soil reinforcement of base courses, construction of retaining walls, and sealing layers.

One of the main environmental benefits of using geosynthetics is the reduction in the use of natural or manufactured resources such as concrete. Traditional construction methods often require excavation and transportation of large quantities of soil, rock, and other materials. By contrast, geosynthetics can be used to enhance the properties of existing soils, minimizing the need for additional materials. This significantly reduces the carbon footprint and improves the sustainability of construction projects.

Case studies are presented to illustrate the benefits of geosynthetics in practice. The paper concludes that geosynthetics can provide significant environmental and economic benefits in construction and should be widely considered in construction projects.

Keywords: Geosynthetics · Sustainability · Recycling

1 Introduction

The construction industry has a significant impact on the environment, and choosing sustainable methods and materials can help reduce its carbon footprint. Geosynthetics, a versatile and eco-friendly construction material, have been found to be effective in reducing greenhouse gas emissions and minimizing the environmental impact of construction projects. Studies have shown that the use of geosynthetics can significantly reduce CO_2 emissions in civil engineering projects, such as retaining structures, trafficked embankments, drainage, and protection walls (Niall et al., 2010; Frischknecht et al., 2011; Sulyman et al., 2016; Brcan et al., 2022). Additionally, geosynthetics can be used for soil stabilization, filtering or binding hazardous substances, and extending the service life of infrastructure. To ensure the sustainable use of natural resources and promote the use of environmentally sustainable products, regulations such as Annex 1

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of Regulation No 305/2011 [1] require the use of Environmental Product Declarations (EPDs) to assess the environmental impact of construction works. Geosynthetics made from recycled polymers, such as recycled PET, are becoming increasingly popular due to their eco-friendliness and cost-effectiveness. Overall, geosynthetics can be a valuable tool for sustainable construction practices, and their use can contribute to a more environmentally friendly construction industry.

2 Environmental Aspects of Construction Projects

2.1 Transportation

Transport is a crucial factor in civil engineering projects, as it can greatly impact the environment and nearby communities. Noise, dust, and vehicle emissions can cause air pollution and health problems. To address these issues, optimizing logistics and using modern trucks meeting EU standards, such as EURO 5 and 6, can help [9]. Alternative transport methods, like electric vehicles and rail transport, can also reduce the impact.

2.2 Construction Machinery

Construction machinery can have significant environmental and community impact. To reduce noise, dust, emissions, and energy consumption, modern equipment meeting EU standards for emissions and energy consumption should be used. Selecting the right equipment and optimizing the coordination of the equipment chain can also help. Staff training in economical driving and the use of particle filters are additional methods to minimize environmental impact. Lastly, selecting eco-friendly construction methods and using noise barriers can further mitigate the impact of construction machinery.

2.3 Construction Materials

Material use in civil engineering projects has significant environmental impacts, including energy consumption, raw material use, hazardous substances, waste, and water consumption. Using recycled materials, avoiding waste, selecting environmentally friendly materials, managing hazardous materials, and separating waste can all help reduce the impact.

2.4 Site Equipment and Construction Area

Construction sites and areas can significantly impact civil engineering projects and the environment. Factors such as energy consumption, waste, water use, soil protection, and biodiversity must be considered. One approach to reducing environmental impact is to use green electricity and implement soil protection measures. Proper waste separation and staff education can also help minimize negative effects.

3 Role of Geosynthetic Materials

Geosynthetics are a versatile and environmentally friendly type of construction material that can be used for a wide range of applications. They have the potential to partially replace steel and concrete elements that require a lot of energy to produce, which can help conserve natural resources and reduce greenhouse gas emissions. Additionally, geosynthetics can help reduce soil excavation and minimize the need for large mass transports, which can reduce the environmental impact of construction projects. They can also be used to seal and separate contaminated sites from the environment, filter or bind hazardous substances, and extend the service life of infrastructure.

For example, the choice of liner material used in landfill capping can have a significant impact on transportation costs and environmental impact. A conventional clay liner with a typical thickness of 50 cm requires around 175–225 tipper trucks to be transported in order to cover a 4500 m^2 area. This results in high transportation costs and increased greenhouse gas emissions. However, the same area can be covered using a bentonite clay liner, where only 22 rolls (5.1x40.0 m) are needed. Remarkably, all 22 rolls can fit in just one truck, significantly reducing transportation costs and the corresponding environmental impact. Therefore, using a geosynthetic bentonite clay liner for landfill capping can be a more cost-effective and environmentally friendly solution.

4 Estimation of Environmental Impact

4.1 Life Cycle Assessment

Life Cycle Assessment (LCA) [5] is an important tool that evaluates the environmental impact of a product or system throughout its entire life cycle, from raw material extraction to disposal. A general structure of a LCA on construction materials is shown in Fig. 1.

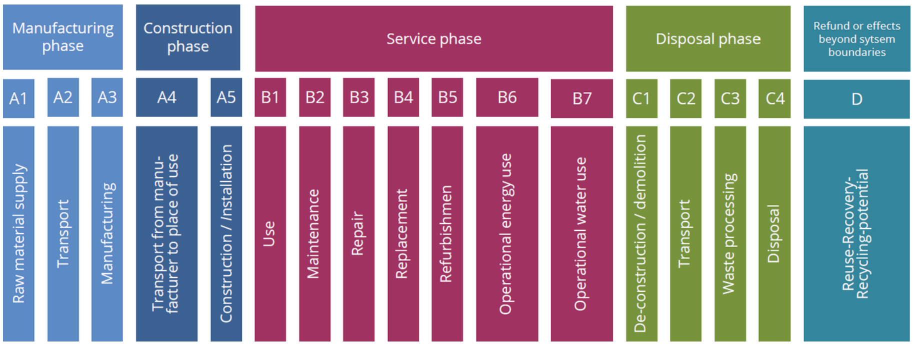

Fig. 1. Life Cycle Assessment (LCA) phases [8]

The data from phases A1 to A3 of a product LCA provides information on the environmental impact of products from "Cradle to Gate", i.e. it includes the supply of raw materials, transport and production processes. The range of phases A1 to C4 covers the entire life cycle of a product, from raw material extraction to end-of-life disposal, and is called "Cradle to Grave". If the product in question can be refunded or efferded, i.e. reused or fully recycled, phase D will provide the environmental impact data for it.

4.2 Environmental Product Declarations

Annex 1 of Regulation No 305/2011 is an important section of the European Parliament and Council's legislation regarding construction works. One of its key elements is §7 [1], which emphasizes the need for sustainable use of natural resources in the design, construction, and demolition of construction works. This means that construction works should be undertaken in a way that minimizes the depletion of natural resources and reduces the environmental impact. The basic requirement for sustainable use of natural resources should consider the use of raw and secondary materials that are environmentally compatible. Additionally, the regulation stresses the importance of using Environmental Product Declarations (EPD) to assess the sustainable use of resources and the impact of construction works on the environment, whenever they are available. By incorporating these principles, Annex 1 [1] aims to promote sustainable development and protect the environment while ensuring the safety and functionality of construction works.

EPDs provide standardized information on a product's environmental impact in kg of CO_2 eq. Per m2 over its life cycle and are based on internationally recognized standards, e.g. ISO 14025 [7] and EN 15804 + A1 [8]. EPDs can be used in project specifications as a tool for communicating the environmental performance of a product to the project team and stakeholders. They be used to increase transparency and accountability in product selection and promote the use of environmentally sustainable products in project specifications by comparing the environmental performance of different products in the same category, allowing the project team to select materials that have lower environmental impact. It is essential to ensure that the EPDs and LCA data are accurate, reliable, and based on standardized methodologies to ensure fair comparisons between the materials.

5 Related Studies

5.1 WRAP Study

Construction methods have a significant impact on the environment, and choosing the right method can help to reduce the carbon footprint of civil engineering projects. In a study conducted by WRAP [2], several construction methods were compared to determine their carbon footprint in civil engineering projects. The study looked at the environmental impact of retaining structures, trafficked embankments, drainage of retaining structures, and protection walls. For retaining structures, the traditional methods of using reinforced concrete retaining walls and sheet pile walls were compared to the geosynthetic reinforced soil walls. It was found that the use of geosynthetics reduced CO_2 emissions by up to 80%. In the case of trafficked embankments, the use of geosynthetic reinforced local soil was compared to the traditional method of using imported rock material. The study found that the use of geosynthetics resulted in a 30% reduction in

CO_2 emissions. For the drainage of retaining structures, the use of hollow concrete blocks was compared to the geosynthetic drainage composite. The study found that the use of geosynthetics reduced CO_2 emissions by up to 28%. Finally, for protection walls, the use of imported rock and gabion materials was compared to the geosynthetic reinforced local soil. The study found that the use of geosynthetics reduced CO_2 emissions by up to 89%. Overall, this study highlights the importance of considering different construction methods and their environmental impact when planning civil engineering projects, as the use of geosynthetics can significantly reduce CO_2 emissions. The results of the study are summarized in Table 1.

Table 1. Results of the WRAP study (2010) [2].

Case study	Originally intended construction method	Geosynthetic solution	CO_2 reduction total
Protection wall	Approached rock material and gabions	Geosynthetic reinforced soil	89%
Traffic embankment	Approached rock material	Geosynthetic reinforced soil	30%
Retaining wall	Reinforced concrete	Geosynthetic reinforced soil	70%
Retaining wall	Reinforced concrete	Geosynthetic reinforced soil	57%
Retaining wall	Sheet pile wall	Geosynthetic reinforced soil	80%
Drainage for retaining wall	Hollow concrete blocks	Geo-composites	28%

5.2 EAGM Study

The EAGM study conducted in 2011 [3], compared different construction methods to determine their environmental impact. The study focused on four areas of civil engineering: filter system underneath a traffic route, soil stabilization of a road substructure, drainage layer in landfill surface sealing, and retaining structures. For each area, several designs were evaluated. Some designs utilized traditional construction methods while the others used geosynthetics. The study found that the use of geosynthetics significantly reduced the environmental impact of construction in all areas. For instance, when using geosynthetics as filters under traffic routes, the environmental impact was reduced by 85% in general, energy consumption was reduced by 85%, and greenhouse gas emissions were reduced by 89%. The study underscores the importance of using sustainable construction methods in civil engineering projects to mitigate their environmental impact. By utilizing geosynthetics, engineers can significantly reduce the carbon footprint of construction projects and contribute to a more sustainable future. The outcomes of the study are shown in Table 2.

Table 2. Outcomes of the EAGM study (2011) [3].

Case study	Originally intended construction method	Geosynthetic solution	Reduction of environmental impact in general	Reduction of energy consumption	Reduction of greenhouse gas emissions
Road filter systems	Mineral gravel filter system	Filter system with geosynthetics	85%	85%	89%
Stabilization of road subgrade	Without stabilization or stabilized with cement or lime	Geosynthetic reinforced	5–10%	n/a	32%
Drainage in landfill capping	Mineral drainage	Geosynthetic drainage	50%	56%	67%
Retaining walls	Reinforced concrete	Geosynthetic reinforced soil	52–87%	75%	85%

5.3 KIWA-FH Münster Study

A recent study by FH Münster and KIWA in 2022 [4] compared the LCA between geogrid-reinforced and conventional bridge abutments, using the example of the Stokkumer Strasse overpass bridge over the A3 motorway. The study examined two abutment designs: conventional reinforced concrete and geosynthetic reinforced soil solution. The geosynthetic-reinforced earth structures were chosen as the design for the bridge abutments due to their faster and cost-effective construction, and potential advantages over conventional reinforced concrete construction methods in terms of LCA. Thanks to the strong teamwork of all the companies and parties involved, the bridge was completed in just 80 days, occupying a small footprint and with no restriction of traffic on the A3 motorway during the construction works.

The study aimed to address the extent to which geogrid-reinforced bridge abutments can be evaluated as resource-saving or environmentally friendly over their life cycle compared to conventional bridge abutments. It also examined how the recycling of geogrids affects the environmental impact according to EN15804 + A2 compared to the state-of-the-art disposal method of thermal recycling. By examining both the environmental and economic impact of both types of bridge abutments, the study provides valuable insights into sustainable bridge design and construction.

In the executed design of the bridge abutments, two facing types were used: a half gabion solution filled with granular material for the lateral face and prefabricated concrete panels for the front and partially lateral face. The choice of concrete panels for the front and partially lateral face was made based on the fire resistance requirements of the German highway regulations, while the half gabion facing provides a stone look and is less carbon-intensive than concrete solutions.

A comparative study was conducted on both abutment designs, and some conclusions can be drawn from the study. In the life cycle phases A1 to A3, which include raw material supply, transport, and manufacture of the products, the core environmental indicators dominate for both abutment designs. The geosynthetic-reinforced abutment construction shows a reduction of about 40% in CO_2 emissions compared to the conventionally manufactured abutment construction. During the manufacturing phases A1 to A3, the CO_2 reduction is approximately 46%. The elimination of soil improvers like the lime-cement mixture can contribute to a further CO_2 saving of about 20% relative to the overall balance of the geosynthetic-reinforced bridge abutment.

Although a longer span of the bridge superstructure must be considered for a geosynthetic-reinforced abutment, resulting in an additional CO_2 emission of about 7,300 kg CO_2 eq., this design still reduces the CO_2 emissions for the entire construction, including the superstructure, by approximately 42% in phases A1 to A3 compared to a conventional abutment construction. Finally, there is potential for CO_2 savings through the reuse of reclaimed geosynthetics, depending on the type of processing required for reuse. Overall, these findings offer valuable insights into the environmental impact of different bridge abutment designs and can help inform sustainable construction practices.

6 Utilization of Recycled Polymers

The properties of recycled polymers may not always be equal to those of virgin polymers. The properties of a recycled polymer depend on the quality of the recycled material, the type and level of contaminants, and the recycling process used. In general, the mechanical properties of recycled polymers are lower than those of virgin polymers, but the exact extent of degradation varies depending on the polymer type, the processing method, and the extent of recycling. For example, polyethylene terephthalate (PET) is commonly recycled and can retain most of its mechanical properties when recycled, depending on the level of impurities and the processing conditions used. It is important to carefully consider the type and quality of recycled polymers used in construction projects and to ensure that they meet the required performance standards.

Construction materials made from 100% recycled PET can be a sustainable and environmentally friendly alternative to traditional construction materials or materials made from virgin PET. Despite not being currently included in the current CE regulations, these products offer the same properties and performance as their non-recycled counterparts, and an update to the regulations has already been initiated.

One of the key benefits of using geosynthetics made from recycled PET is the significant reduction in CO_2 emissions compared to using virgin materials. For example, for every kilogram of PET recycling yarn used, approximately 4.3 kg of CO_2 emissions can be saved, equivalent to driving 33 km in a car emitting 130 g of CO_2 per km. When applied to the geotextiles covering an area the size of a football field, approximately 5500 kg of CO_2 emissions can be saved, equivalent to driving 42400 km in a car.

Currently, the most common applications for geosynthetics made from recycled PET include base course reinforcement, asphalt reinforcement, soil reinforcement for retaining structures, embankments on soft soils or piled embankments, and sinkhole overbridging. These materials can also be reused in asphalt reinforcement during demolition or milling. The use of construction materials made from recycled PET presents a viable option for sustainable construction practices in civil engineering projects [6].

7 Conclusions

Geosynthetics are eco-friendly alternatives to energy-intensive steel and concrete elements, reducing excavation, transportation, and environmental impact in construction. European regulations prioritize sustainable use of resources, emphasizing compatible raw materials and secondary products. LCA evaluates construction's environmental impact, while EPDs provide standardized information [5].

In 2010, a WRAP study [2] compared traditional methods to geosynthetics in several areas of civil engineering, including retaining structures, trafficked embankments, drainage of retaining structures, and protection walls. The use of geosynthetics significantly reduced CO_2 emissions in all areas, by up to 89%.

The 2011 EAGM study [3] found that using geosynthetics significantly reduced environmental impact in all considered applications, with reductions of up to 85% in energy consumption and 89% in greenhouse gas emissions.

A comparison was made in 2022 by KIWA-FH Münster [4] between the environmental impact and economic cost of conventionally reinforced concrete bridge abutments and those reinforced with geosynthetics. The study found that the geosynthetic-reinforced abutment construction showed a reduction of about 40% in CO_2 emissions compared to the conventionally manufactured abutment construction.

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